

# Cartographic documents for web modeling and representation of indoor mapping with interactive environments

[Extended Abstract] \*

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## ABSTRACT

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## Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous;  
D.2.8 [Software Engineering]: Metrics—*complexity mea-  
sures, performance measures*

## General Terms

Theory

## Keywords

ACM proceedings, L<sup>A</sup>T<sub>E</sub>X, text tagging

## 1. INTRODUCTION

CARATTERISTICHE E SPUNTI:

\*A full version of this paper is available as *Author's Guide to Preparing ACM SIG Proceedings Using L<sup>A</sup>T<sub>E</sub>X<sub>2</sub> $\epsilon$  and BibTeX* at [www.acm.org/eaddress.htm](http://www.acm.org/eaddress.htm)

<sup>†</sup>Dr. Trovato insisted his name be first.

<sup>‡</sup>The secretary disavows any knowledge of this author's actions.

<sup>§</sup>This author is the one who did all the really hard work.

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- CONNESSIONE CON I SENSORI PER LA RILEVAZIONE DELLA POSIZIONE DEI VISITATORI

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The remainder of this document is organized as follows. In Section II is provided an overview of the state of the art. Section III is devoted to describe the novel cartographic document proposed, while section IV introduces the underlying mathematical structure. Section V reports about the tools and instruments developed specifically for the web, focusing on software architecture, implemented algorithms and real applications. Section VI describes one use case of both document format and software tools. Finally Section VII proposes some conclusive remarks and future developments.

## 2. STATE OF THE ART

Researches about the cartographic representation of indoor environments are numerous and at the same time heterogeneous regarding to the strategies applied. The information sources used are different, depending on the approach, the produced solution can be more or less precise. In some cases the information is obtained with automatic or semi-automatic processes from files that describe the architectural structure of a building such as BIM (Link a BIM) and/or IFC(Link a IFC) (Danesi), in others image processing is used to extract topological information from floor plan images (Panzieri). As a last approach, descriptive parameters will be redefined from zero, as the current representation strategies concerning a use beyond the mere consultation are considered inappropriate. A recurring topic among the use of cartographic information is the indoor navigation(Panzieri, Polacch e Danesi). The proposed approaches are very different in this case too, and based on different

strategies with some basic elements in common. A recurrent solution is based on the representation of the routing information as a graph having a node for each PoIs and an edge for each connection between them. In some cases the edges are weighted in function of euclidean distance. The detail level of the graph and hence the effective practicality of the calculates paths, can vary depending on the technique and the design choices applied, but in general most of the proposed solutions (all those calculate paths) retrieve information from architectural structure. An inevitably theme connected to the navigation is the location of users. All the related works agree on the inadequacy of GNSS in indoors contexts, due to the significant redaction in the signal quality. To locate the exact position within a building, the currently most used techniques are based on fingerprinting and triangulation of radio signals (WiFi, Bluetooth, etc.) flanked by more original solutions based on, for example, image recognition (arabi). The proposed solutions for the movements tracking range from the creation of ad hoc devices (Panzieri) to the use of sensors already present in many smartphones for inertial tracking (Arabi).

(DANESI: Boysen M. de Haas C., Lu H., Xie X., Pilvinyte A., Constructing Indoor Navigation Systems from Digital Building Information, ICDE Conference, pp. 1194-1197, 2014.) (ARABI: Al Delail B., Weruaga L., Zemerly M.J., Ng, J.W.P., Indoor localization and navigation using smartphones augmented reality and inertial tracking, IEEE, pp. 929-932, 2013.) (POLACCHI: Gotlib D., Gnat M., Marciniak J., The Research on Cartographical Indoor Presentation and Indoor Route Modeling for Navigation Applications, International Conference on Indoor Positioning and Indoor Navigation, 2012.) (PANZIERI: Faramondi L., Inderst F., Panzieri S., Pascucci F., Hybrid Map Building for Personal Indoor Navigation Systems, IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), pp. 646-651, 2014.) (CINESI: Bian W., Guo Y., Qiu Q., Research on Personalized Indoor Routing Algorithm, 13th International Symposium on Distributed Computing and Applications to Business, Engineering and Science, pp. 275-277, 2014 )

## 2.1 GeoJSON

GeoJSON is a format for encoding a variety of geographic data structures. GeoJSON supports the following geometry types: **Point**, **LineString**, **Polygon**, **MultiPoint**, **MultiLineString**, and **MultiPolygon**. Lists of geometries are represented by a **GeometryCollection**. Geometries with additional properties are **Feature** objects. And lists of features are represented by a **FeatureCollection**.

GeoJSON is good for geographic mapping application, but not for indoor application. There is a GeoJSON variant suitable for indoor app.

## 2.2 Experiences on Indoor JSON

IndoorJSON is a GeoJSON variant used by indoor.io toolset to define indoor maps. IndoorJSON may consist of any number of **Features** and/or **FeatureCollections**. All **Features** are interpreted similarly regardless of their grouping into nested **FeatureCollections**. IndoorJSON supports all GeoJSON geometry types.

## 3. ADVANCES ON CARTOGRAPHICS DOCUMENT STANDARDS

**HIJSON** (**H**ierarchical **I**ndoor **J**SON) is a GeoJSON variant. A HIJSON document reveals at least three major enhancements above the actual state of the art in indoor cartographic documents:

1. Hierarchical structure;
2. Metric local coordinate System;
3. Semantic extensions;

### 3.1 Hierarchical structure

Unlike other formats like GeoJSON or IndoorJSON, HIJSON organizes its elements in a hierarchical structure, where every element represent a potential container for other elements. This structure allows a clear and logical organization of the elements inside the structure, and at the same time make it possible to use a relative, local, metric coordinates system.

### 3.2 Metric local coordinate System

In GeoJSON all the positions are expressed in geographical coordinates (usually WGS84). Although this can be useful for outdoor geographical representations, it is not the best solution for indoor descriptions. In HIJSON all the coordinates are expressed in a relative system based on the hierarchical structure. The shape of all elements is described starting from origin, and then two vectors (translation and rotation) describe the position relative to the origin of the parent element. By this way it is possible to describe the position of a piece of furniture by specifying its distance from the origin of the room, that is obviously more convenient than describing its geographical coordinates. Another advantage is represented by the adoption of a metric reference. A recursive process that computes intermediate transformation matrixes can then produce a standard GeoJSON representation, that can be visualized on any standard viewer.

### 3.3 Semantic extensions

Every HIJSON Element has a property that describes its class. This information allows the adoption of semantic extensions by the software that manipulates the HIJSON data. In the Javascript library developed to manage HIJSON documents, different classes are instantiated to represent HIJSON Nodes, which acts differently by the adoption of polymorphic methods. In order to extend the possibilities in representation and interaction, it is sufficient to define new classes that reflects new categories of HIJSON Elements.

## 4. DOCUMENT STRUCTURE AND VALIDATION RULES

A single HIJSON document is composed of different parts:

- configuration: a JSON object containing parameters and settings useful for the building representation. In particular three points of the local reference system are mapped to three couples of geographical coordinates. This information allows the computation of the transformation matrix used to translate the local coordinates to global ones.
- one or more data collections: each of these lists is given in the form of a GeoJSON **FeatureCollection**, containing a number of HIJSON Elements. Since HIJSON Elements adhere to the GeoJSON format, each collection

can be accepted by a GeoJSON validator. HIJSON introduces some additional rules that allow the adoption of this format for indoor representation. Below is given a sample of HIJSON Element, with the description of the main differences from a standard GeoJSON Feature.

```
{
  "type": "Feature",
  "id": "room_0.1",
  "geometry":
  {
    "type": "Polygon",
    "coordinates":
    [
      [ [0, 0], [11, 0], [11, 19], [0, 19] ]
    ]
  },
  "properties":
  {
    "class": "room",
    "parent": "level_0",
    "description": "Office of Mr. Smith",
    "tVector": [10, 20, 0],
    "rVector": [0, 0, 90]
  }
}
```

The first additional requisite above the GeoJSON format rules is the necessity of a unique ID, necessary for the referencing by possible child elements. The Geometry types allowed are **Point**, **LineString** and **Polygon**. Each geometry type is used to represent particular categories of elements (e.g. Polygons for levels and rooms, LineString for walls and doors, Point for furniture, etc.). The geometry coordinates are expressed in meters, and for convention starting at the bottom-left of the element. Unlike GeoJSON, where all the properties are optional, in HIJSON some attributes are mandatories:

- **class**: represent the element category, used to instantiate the appropriate semantic class;
- **parent**: contains parent's id of the nodes. The reason of the unique id depends on this property. The HIJSON Tree is created on the base of parent property;
- **tVector** and **rVector**: represent the translation and rotation relative to the parent element. The measure unit for translation is meter and for rotation is grades.

The definition of other properties is mandatory on the base of the class of the element: For example the classes that defines internal or external walls require a **connections** array, containing the IDs of the adjacent areas. This information is used by the connector children of the element, like doors, to identify the areas linked together. These connector elements, like doors, are identified by a boolean **connector** property set to true.

Optional fields can be added to improve the precision of the representation. Given the nature of the GeoJSON format from which HIJSON derives, the elements are represented by their 2D shape, like on a planimetry. To assign a value to the height of the object, intended as third dimension, the property **height** can be used.

A **description** property can provide additional information about the element.

Additional optional fields can be freely added, to enrich and extend the expressivity of the representation.

## 5. APPLICATIONS

QUESTA SEZIONE PRECEDENTEMENTE INSERITA DENTRO WEB TOOLKIT VORREI SPOSTARLA FUORI O DENTRO ADVANCES ON CARTHOGRAPHICAL STANDARDS DOCUMENT PONENDOCI COME OBIETTIVI DI DEFINIZIONE DEL DOCUMENTO IL COMPLETO SUPPORTO ALLE APPLICAZIONI ELENcate (ANCHE PER BILANCIARE LA LUNGHEZZA DELLE VARIE SEZIONI: IL TOOLKIT VIENE FORSE TROPPO LUNGO SE TENIAMO ANCHE APPLICATION DENTRO) DOVESSIMO DECIDERE DI SPOSTARE LA TRATTAZIONE DEVE SOLO DESCRIVERE IN GENERALE COSA CI SI ASPETTA DA OGNUNA DELLE APPLICAZIONI. VALUTIAMO.

### 5.1 IoT monitoring

Every element in 2D map or in 3D model is interactive and the user can ask for information. In every class there is a method that gets information and send that to the client. The modularity of *nome del software* permits to show particular information with regard to the object. There are two groups of objects: simple and smart. If the object is smart, it can send data in real time through its sensor (e.g. if the object is a thermostat, the user can see the temperature in the room and can turn on/off the heating). If the object isn't smart, the system can show static information (e.g. for fire Extinguisher, the system shows the last date of checking).

### 5.2 Realtime multi-person tracking

The system can be used for access monitoring. On 2D map will be a marker for each person in the building, whereas on the 3D model will be a 3D model of user. With an appropriate system of indoor localization, every person sends its position in real time. The 2D map and the 3D model is automatically refreshed. The user can ask for information about person, in function of the use of the system.

The communication of the current position happens with the socket.io library. Every user sends an object like this:

```
currentPosition = {
  coordinates: [x, y],
  levelId: level-ID
}
```

For every change of the coordinates or level, an *emit* event will be generated, according to the socket.io library, which sends to the server the new current position. The server sends to the connected client the updated current position of the users connected. In the client-side, when the *on* event of socket.io library is hit, there will be a refresh of the marker in 2D map and the 3D model in the 3D representation. With Observer pattern implemented in socket.io library, it is possible to have a realtime multi-person tracking. This system permits to be independent from the tool that gets the position of the users: the only requisite is to send the position like the object described above.

AGGIUNGERE SINTETICA DESCRIZIONE DEL PROTOCOLLO WEBSOCKET UTILIZZATO SPECIFICANDO LE EFFETTIVE CAPACITA' DELLO STRUMENTO.

### 5.3 Crossfloor user navigation

With the weighted adjacency matrix, the user can choose two nodes that represent respectively the start and the end point. The system calculates the optimal path by Dijkstra's algorithm and shows this with a polyline in 2D map. To pass through different floors, the path leads to stairs or elevators. All the nodes of the same elevator are connected among them and their distances is set to 0. Otherwise the connections through the stairs are characterized by the nodes of two different levels; their weight of this portion of path is set to the distance between these nodes. Therefore the subgraph that characterized stairs or elevator is complete.

## 6. HIJSON WEB TOOLKIT

The HIJSON Web Toolkit comprises the reference architecture and the relative software implemetarion of the web platform that allows to working with HIJSON documents. The toolkit responds to the needs of an extendable, customizable, and scalable framework which provides at the same time IoT monitoring, realtime multi-person tracking and crossfloor user navigation.

Expandability and customizability derives from both design choises and HIJSON inherent characteristics, the possibility of semantic extensions. Scalability is directly borrowed from technologies used for the software development: *JavaScript* language, using *Node.js*, in particular *Express.js* as backend framework, exploiting the power of WebSocket protocol through the *Socket.io* library.

Being supported by the web as bearing platform, the toolkit exposes also an highly availability: it is so simple to use as to visit a website, both from desktop or mobile devices, without explicit requirements to install any software from proprietary stores (access to which is often denied from business devices).

The HIJSON Web Toolkit offers the overal client/server architecture and a convinient, highly intractive user interface, leaving aside the specific indoor positioning system and the IoT sensors, to deal with a robust interface is provided and described in the following seciton.

SPECIFICARE CHE TECNOLOGIE RISIEDONO DIETRO OGNI ASPETTO DELL'INTERFACCIA: PROBABILMENTE OCCORRE RIMETTERE IN QUESTA SEZIONE LA SOTTOSEZIONE "APPLICATIONS"

### 6.1 HIJSON Class definition

To exploit the possibilities offered by HIJSON Web Toolkit, along with the HIJSON document, some custom dynamic behaviours must be described. These behaviours encapsulate the specificities relative to comminucation procols with the sensors as well as user interaction peculiarities. The interface for these behaviours is the HIJSON Class.

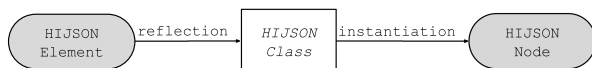


Figure 1: "HIJSON Element/Class/Node relashionship"

Each HIJSON Element of the input HJSON document has a dynamic counterpart inside the toolkit called HIJSON Node, instantiated according to the relative HIJSON Class through relfection methods (see picture XXXXX).

To specify a new HIJSON Class means to extend the toolkit to deal with a new class of HIJSON Element.

To extend the toolkit to deal with a new class of HIJSON Element is required to to specify a new HIJSON Class, defining the following properties and methods:

- **in\_graph**: a boolean value to express if the element is an approachable point in the graph paths;
- **in\_2D\_map**: a boolean value to express if the element is wanted in the 2D map;
- **get2DStyle**: a method that returns the 2D map appearance of the element, essentially HTML and CSS code;
- **get3DModel**: a method that returns the 3D model appearance of the element, a THREE.js Object;
- **getWidget**: a method that returns the information widget, a React Component;
- **getProxy**: a method that returns server side proxy which encapsulate IoT sensor communication protocol, a Node.js module.

User's needs for new indoor elements, different sensor equipment, alternative representation on 2D or 3D viewport are accepted by the definition of new HIJSON Classes that allows in this way single point custom extension of the toolkit capabilities.

### 6.2 Architecture

Like the vast majority of the web based application, the toolkit exposes an overall architecture that is inherently *client/server*. In particular, two different type of possible client are identifiable: the *Supervisor* client and the *Explorer* client. Both of them connect to the same server.

The indoor space described by the HIJSON document provided as input is processed by the server (cfr. PROCESSING PIPELINE). After that any connecting *Explorer* client, presumably through a mobile device, will be provided with the information to perform crossfloor navigation of the building, while reporting user position to the server. The server will feed any connecting *Supervisor* client with users positions, along with data from sensor-equipped things present in the environment, realizing the IoT monitoring and the realtime multi-person tracking.

#### 6.2.1 Server Architecture

The architecture of the server is depicted in XXXX. A web server module is responsible for listening to connecting clients. Each client connection is handled by the web server module providing all the required resources and opening one websocket channel, through which will flow *Explorer* and/or *Supervisor* communication protocol data. In particular, **multi-person tracking** module receives position data from *Explorer* clients. It aggregates and sends these information to connected *Supervisor* clients through the websocket channel, using a simple but realible protocol later described. Indipendence from particular IoT sensor equipment communication protocol is achieved by the **smart things proxies** module through the proxies modules obtained by the HIJSON Class definition (**getProxy** method previously described).

#### 6.2.2 Explorer client architecture

The client *Explorer* architecture is generally deployed on a mobile device, usually supplied to a user who needs to be

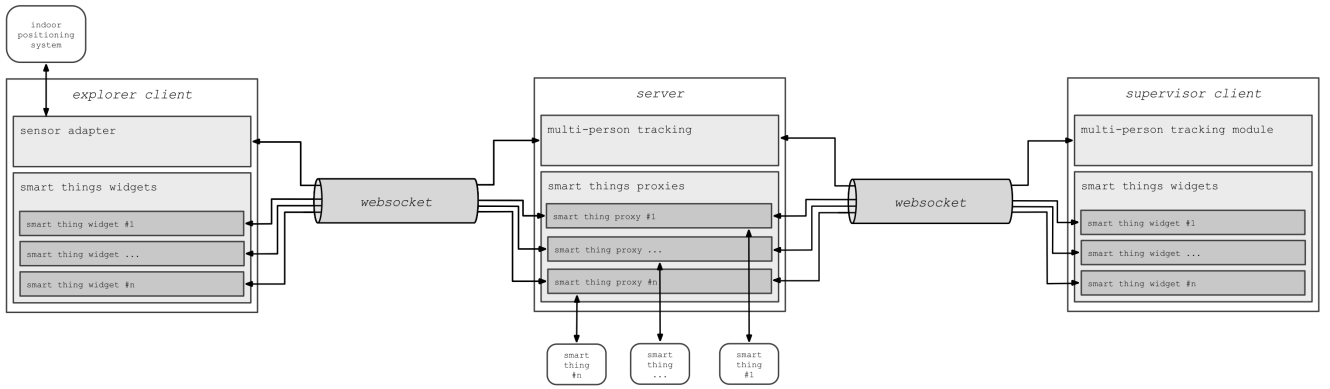


Figure 2: “HIJSON Web Toolkit architecture”

routed across the environment described by HIJSON document. The **sensor adapter** module encapsulates the communication logic with the indoor positioning system. The presence of this module ensures independence from particularly technology allowing client *Explorer* to rely on different indoor positioning systems: INDICARE ESEMPI SENSORISTI E CUTTING EDGE DI POSIZIONAMENTO INDOOR. INTRODURRE IL PROBLEMA DELLA COMUNICAZIONE A LIVELLO API DEL BROWSER CON SENSORISTICA PER LA RILEVAZIONE DELLA POSIZIONE.

Every time the **sensor adapter** observe a perceptible modification in user position sends the new position information to the server through the single opened websocket, using the a message with the following syntax:

```
currentPosition = {
  coordinates: [x, y],
  levelId: level-ID
}
```

Relevant information includes, beside current coordinates, the indication of the story of the possibly multilevel building the user is in. The **smart things widgets** module being in common with the client *Supervisor*, has been treated in the next section.

### 6.2.3 Supervisor client architecture

The Client *Supervisor* architecture shows two modules. The first one, the **multi-person tracking** module, is responsible to receive through the websocket, from the server information about explorers of the environment, showing them in the user interface. The second module, the **smart things widget** communicates with the server to propose to the user realtime information about sensor-equipped objects in the environment. Data passes through the single websocket opened between the server and every *Supervisor* Client. Rely on a naive but effective communication protocol, each smart thing widget exchange data only with respective smart thing proxy on the server. To ensure the data is sent only when the user requires the information relative to a specific smart thing, a widget lifecycle protocol is implemented: it is based on the 4 events **on\_before\_show**, **on\_show**, **on\_before\_hide**, **on\_hide** triggered, as suggested by their names when a widget is shown or hidden. When the user requires information about a smart thing, its widget has to be rendered, but **on\_before\_show** the server is notified to

connect via relative proxy to the sensor. Once connected, the server begin to send data via websocket. Received data is shown through the widget to the user. When done, or **on\_before\_hide** event of the widget, a notification is sent to the server announcing to stop sending data and the proxy close the connection to the sensor. Widget lifecycle protocol ensures that only requiring data is sent from the server to the client.

### 6.3 HIJSON processing pipeline

Each time a new HIJSON document is submitted to the server, it is passed through the **HIJSON processing pipeline**, where it is subjected to a sequence of preliminary transformations.

The application of the transformation pipeline has a double aim. The first one consists in generating the graph of valid paths between all the interesting HIJSON elements. The second aim is the generation of one *GeoJSON* document for each story of the building described by the HIJSON document. In this way any connected client can be provided with a bidimensional plant for each level of the building that it can visualize through any compliant *GeoJSON* viewer.

HIJSON processing pipeline (as pictured in figure AGGIUNGERE RIFERIMENTO) is composed by 6 elaboration stages. In the following are detailed operations executed by each stage, which are, in the order: *validation*, *georeferencing*, *parsing*, *graph paths generation*, *2D layers generation*, *marshalling*.

1. **validation** - The first one is the validation stage. In order to begin with the effective transformations the input HIJSON document must be compliant with the rules defined in (AGGIUNGERE REF TO PARAGRAFO REGOLE DI VALIDITA'). In the case the validation stage fails, processing aborts and do not continue to following stages. If the stage success, the output for the next stage is a validated HIJSON.
2. **georeferencing** - In the second stage, in order to allow for continuous outdoor/indoor navigation, the system needs to compute the georeferencing matrix, a linear operator able to transform local coordinates into global coordinates (referred to world coordinate system as latitude and longitude measures) and viceversa. This task is accomplished by solving a linear system obtained from information contained in HIJSON con-

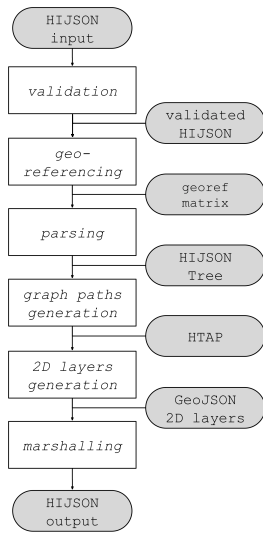


Figure 3: “HIJSON processing pipeline”

figuration part and precisely from the correspondence of three real word points to three points included into the HIJSON document.

3. **parsing** - The parsing stage, takes the validated and georeferenced HIJSON as its input, that as illustrated before can be thought of as a list of HIJSON Elements, parses them and produce an instance of HITREE. The HITREE is an object in memory representing the tree hierarchical structure of the building described by the HIJSON document.
4. **graph paths generation** - The fourth stage is in charge of the generation of the graph paths. This aim is accomplished according to the algorithm described in (AGGIUNGERE RIFERIMENTO A ##### Automatic generation of valid paths). The graph paths will be useful afterwards to compute valid paths from couple of point of interest on the graph. Once the graph paths has been computed, the input HITREE is augmented with paths information, becoming what has been called an HTAP (HITREE Augmented with Paths). Augmentation always takes place as leaf nodes added as children of a specific (e.g. “room”) level.
5. **2D layers generation** - The fifth stage is the generation of GeoJSON layer. For each level, the system generates one geoJSON layer that will be use for the creation of 2D map. Each layer contains the children of ‘level’ node in the HITREE. Every class contains a boolean value that is used to choose which class will be a part of geoJSON layer. Every element has a geographical coordinates calculated by the transformation matrix with regard to the local coordinates of the HIJSON element.
6. **marshalling** - The last stage is responsible of execute a serialization of the the transformed data. Tasks like breaking dependency-loops and stringification are performed, and the output is stored ready to be served to any requiring client.

### 6.3.1 Client

When a client connects to the server, it receives the HIJ-

SON input files, the ready-to-use GeoJSON layers and the weighted adjacency matrix of the graph paths. A very short pipeline of processing is performed by the client, composed by:

1. **Parsing** - Like for the Server-side processing, the HIJSON Elements in the input files are processed and tranformed in HIJSON Nodes, linked together in a hierarchical tree structure.
2. **3D Model generation** - Unlike HIJSON Elements (that are simple Javascript objects), HIJSON Nodes are instances of specific classes, representing a particular category of element in the building. Through a polymorphic method, each node generates a Three.js 3D model of its entity, that is used to assemble a complete 3D Model of the building. The similarities in HIJSON hierarchical structure and Three.js scene graph allow this process to be performed with little effort.

### 6.3.2 Algorithmics: automatic generation of valid paths

(IN QUESTA SEZIONE SI POSSONO AGGIUNGERE EVENTUALI APPROFONDIMENTI DI ALTRI STADI DELLA PIPELINE)

The fourth stage of the processing pipeline is responsible for the generation of a graph of valid paths through the entire model represented by the input HIJSON document. The graph generated according to the algorithm described in the following, although not optimal, ensures a complete coverage of the surface while limiting the numebr of generated nodes. Resulting graph is weighthd on the edges with nodes distances and each node represents alternatively:

- a. standard path node, i.e. a junction node or possibly an endpoint of a path;
- b. connection node, used as subproblem composing element in the divide et impera approach adopted (as described below).
- c. element nodes ie. HIJSON Element (whose HIJSON Class explicitly grants his presence in the graph), typically an endpoint of a path;

Such a graph allows for directions calculations between any two given nodes. Directions are actually computed clientside applying the Dijkstra’s shortes route algorithm on the graph.

Taking advantage of the hierarchical structure of the HIJSON document, and according to the divide et impera approach, the problem of the graph paths generation is splitted in several sub-problems which consist in the computation of the sub-graphs relative to each room, or more generally ambience. The sub-graphs are then linked together through the connection nodes (which in most cases represents doors). The resolution of each sub-problem (as depicted in figure METTERE RIFERIMENTO ALLA FIGURA), is composed by 4 phases:

1. Computation of the walkable area of the ambience: this task is accomplished subtracting area of the possibly encumbrances to the area of the ambience; the result is typically a surface with holes;
2. Triangulation of the walkable area: the computed surface is triangulated taking into account the presence of holes;

3. Identification of graph nodes: for each triangle side completely internal to the area, its midpoint is selected as standard path node;
4. Junction of nodes: nodes relative to the same triangle are then linked together; both element nodes and connection nodes (i.e. doors) are linked to the nearest node in the ambience (i.e. room).

## 7. CONCLUSIONS

We presented HIJSON a GeoJSON extension for indoor mapping TRA GLI SVILUPPI FUTURI: - GENERAZIONE GRAFICA IN AMBIENTE CAD DEL DOCUMENTO HIJSON

## 8. ACKNOWLEDGMENTS

This section is optional; it is a location for you to acknowledge grants, funding, editing assistance and what have you. In the present case, for example, the authors would like to thank Gerald Murray of ACM for his help in codifying this *Author's Guide* and the `.cls` and `.tex` files that it describes.

## APPENDIX

### A. HEADINGS IN APPENDICES

The rules about hierarchical headings discussed above for the body of the article are different in the appendices. In the `appendix` environment, the command `section` is used to indicate the start of each Appendix, with alphabetic order designation (i.e. the first is A, the second B, etc.) and a title (if you include one). So, if you need hierarchical structure *within* an Appendix, start with `subsection` as the highest level. Here is an outline of the body of this document in Appendix-appropriate form:

#### A.1 Introduction

#### A.2 The Body of the Paper

##### A.2.1 Type Changes and Special Characters

##### A.2.2 Math Equations

*Inline (In-text) Equations.*

*Display Equations.*

##### A.2.3 Citations

##### A.2.4 Tables

##### A.2.5 Figures

##### A.2.6 Theorem-like Constructs

*A Caveat for the T<sub>E</sub>X Expert*

#### A.3 Conclusions

#### A.4 Acknowledgments

### A.5 Additional Authors

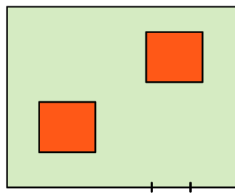
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### A.6 References

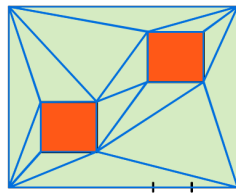
Generated by bibtex from your `.bib` file. Run latex, then bibtex, then latex twice (to resolve references) to create the `.bbl` file. Insert that `.bbl` file into the `.tex` source file and comment out the command `\thebibliography`.

## B. MORE HELP FOR THE HARDY

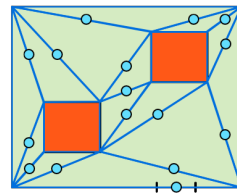
The sig-alternate.cls file itself is chock-full of succinct and helpful comments. If you consider yourself a moderately experienced to expert user of L<sup>A</sup>T<sub>E</sub>X, you may find reading it useful but please remember not to change it.



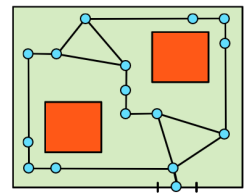
(a)



(b)



(c)



(d)

Figure 4: Graph paths generation: (a) detection of obstacles and computation of walkable area; (b) triangulation of walkable area; (c) identification of graph nodes area; (d) junction of nodes.